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Piaget's life is as interesting as his theory of intellectual development. He was born in France in 1896, published his first article at the age of 11, completed his Ph.D. degree in biology at the age of 21, and subsequently devoted his efforts to study, research and teaching in the psychology of intellectual development. Initially he was interested in exploring the idea that intellectual development resulted from adaptation of the individual to his environment, a concept involving a combination of biology and psychology. As his research progressed, however, he found it necessary to incorporate ideas from the disciplines of formal logic, mathematics, philosophy and epistemology. His first five books brought him considerable attention and he soon became known as an authority in psychology, despite the fact that he had never passed (nor attempted) an examination on the subject. Over the years he has written more than 30 books and over 100 articles in the field of child psychology.

There are basically three points about Piaget that appeal to science teachers. First, Piaget's findings are based on his work in one-to-one situations with children. Extrapolation of Piaget's findings into the school and classroom is relatively easy for teachers to accept compared to findings based on laboratory animals. Second, teachers have been exposed to a great deal of information concerning the social and emotional factors that promote learning, but they have received little help in understanding how children learn. Piaget provides the structure that helps to explain why even highly motivated and emotionally stable students fail to learn certain concepts. Third, and closely related to the second point, Piaget's theory of intellectual development provides the teacher with a frame of reference to interrelate and unify the formerly scattered and disjointed aspects of classroom teaching. Piaget's theory can serve as a guide for making decisions concerning teaching strategies, grouping for instruction, grading, accountability

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and curriculum development. In the words of one science teacher, "Piaget gives us something to shoot for."

PIAGET'S THEORY

Piaget reasoned that understanding the intellectual nature of the adolescent and adult could only be accomplished by studying the child's development from birth through adolescence. Early in his research Piaget became aware of the limitations of standardized pencil-and-paper tests. He began to ask children about their responses to examination questions and found that it was the child's wrong answers, rather than right answers, that provided insight into the child's intellectual nature. He also found that the ambiguity and distortion in oral communication could be reduced if the discussion with the child was in reference to the manipulation of physical objects during the discussion. Thus Piaget developed a series of tasks—now known as Piagetian tasks—to test children's mental abilities.

In the course of administering the tasks to many children of various ages, Piaget found that the intellectual ability of children varied radically from birth to about age 15 years. For example, he found that, on the average, children could not handle problems with more than one variable before age 7 years and could not do abstract reasoning before age 11 or 12 years. Piaget recognized a continuum of intellectual development, but he found it useful to divide the continuum into segments called stages based on the age at which the average child demonstrated a newly acquired intellectual ability.

The stages are known as sensorimotor, age 0-2 years; preoperational, age 2-7 years; concrete operations, age 7-11; and formal operations, age 11 and older. Piaget uses the word operation to mean logical thinking.

Sensorimotor Stage: Age 0-2 Years

During this stage the child begins to develop understanding of his physical environment. He becomes familiar with the feel of different materials such as cloth, sand, paper, wood and clay. The child will discover that he can make things happen. The mobile will move when he shakes the crib and he takes pleasure in making noise by striking a pan with a solid object. He develops the concept of the permanence of an object; early in this stage the child will not look for an object that has been placed out of sight, but generally before the end of the first year, the child will begin to look for an object which was shown and then hidden.

Preoperational Stage: Age 2-7 Years

The preoperational stage can best be understood by reference to the following Piagetian task.

Present a four- or five-year-old child with two unequal balls of clay. Ask him to make the two balls equal. After he agrees that both balls are the same size and contain the same amount of clay, press one ball into the shape of a sausage. Ask him whether one shape has more clay, and, if so, which one? The typical five-year-old child will say that the sausage has more clay. When asked why, the typical response will be that the sausage is longer. If you continue to roll the sausage so that it becomes longer and skinnier, the child may reverse his initial answer and say that the ball has more clay now because the sausage is skinnier.

Success with the Piagetian task requires the child to give integrated consideration to the length and diameter of the sausage. When the sausage becomes longer there appears to be more clay, but the sausage also becomes smaller in diameter, so the two factors compensate for each other. Moreover, the child must be able to reverse the transformation mentally to reconstruct the image of the ball from that of the sausage. And finally the child must realize that, in the process of transformation and mental reconstruction, nothing was added or taken away, so both balls must contain the same amount of clay.

The typical preoperational child cannot perform the task successfully because he can only consider one variable at a time—length ("more clay because the sausage is longer") or diameter ("less clay because the sausage is skinnier"). The child is controlled by his perception. If he centers on length he makes one interpretation, and if he centers on diameter he makes an opposite interpretation. He doesn't recognize the conflict between interpretations because each is made in isolation from the other. Moreover, he cannot make a mental reversal of the transformation to return to the starting point and ascertain that nothing was added or taken away, so both shapes must contain the same amount of clay.

Concrete Operations Stage: Age 7-11 Years

The stage of concrete operations is characterized by logical thinking about personal experience and the physical world. In this stage the child is more consistent in his explanations of phenomena in terms of his direct observations and his interaction with objects. He is able to consider more than one variable at a time and he can reverse a process; consequently, he can mentally transform the sausage of clay back to its original shape and conclude that the amount of clay is conserved. Although his thinking is tied to direct experience in the physical world (concrete objects), he can perform mental operations on past experience and objects that are remote from the immediate situation. This stage constitutes a highly significant improvement in the intellectual development of the child, for his thinking is much more flexible and comprehensive. Instead of skipping from one isolated perception to another, as was characteristic of the earlier stage, the child is able to follow a sequence of changes and reversals.

Formal Operations Stage: Age 11 Years and Older

This is the stage of abstract reasoning. In this stage the child is capable of going beyond the experiential or the actual into the realm of the possible. He can begin by stating a few assumptions or laws and then proceed to formulate propositions. He can manipulate the propositions mentally or symbolically on paper: variables A, B and C play a part; if A and C occur together then X will be possible; if A and B occur together, X will be possible; if B and C occur together Y will be possible; therefore, if X is observed it must be preceded by A and C or A and B, but not B and C. He can think in terms of the propositions and not be restricted to experience and direct observation of objects.

The Genetic Thread

Running through Piaget's entire developmental model is the concept of intellectual development as a result of the interaction of the child and his environment. As the child interacts with his environment, he develops a complex network of mental relationships which constitutes his intellectual structure. Many of the early concepts of time, space, matter and motion are only partially formed and frequently erroneous. As the child continues to interact with his physical world, he gradually perceives the conflicts between his early erroneous concepts and new notions of the real world. Such contradictions tip him off his mental equilibrium so that his intellectual structure changes to accommodate the new concept, returning his structure to equilibrium. Subsequently, various forms of the newly accommodated concept will be assimilated (added without change) into the structure to reinforce the newly accommodated concept. Each time accommodation or assimilation occurs, the intellectual structure of the child returns to successively higher levels of equilibrium and the child builds more complete and complex concepts of his environment.

IMPLICATIONS FOR TEACHING SCIENCE

Piaget stresses that learning results from interaction between the learner and his environment. This means that the process of teaching must begin with the *learner's experience*. A teacher can help a learner to better understand his experience by providing him with an opportunity to concentrate on specific variables and relationships that were previously overlooked or apparently unconnected. If the learner lacks the required background experience, the new concept or knowledge that the teacher wishes to teach may be so remote from the frontiers of his intellectual structure that it appears as an island in an intellectual void. The new knowledge or concept would lack anchorage points, accommodation and assimilation of it would not take place, and at best the learner would attempt to memorize it. Memorization of isolated bundles of knowledge is inefficient because, unless the knowledge is soon tied to the learner's intellectual structure, the possibility of conscious recall will rapidly diminish.

In the event that the learner lacks the proper background experience, the teacher should provide the learner with the opportunity to fill the void by conducting activities that actively involve the learner. Except for general guidelines, teaching should follow experience. Piaget states that if one attempts to tell the learner about the concept, or if the learner reads about it prior to experience, it will be distorted. The old saying, "Proceed from the known to the unknown," is still a good teaching guideline.

Unfortunately the limitations of the school and classroom frequently prevent the teacher from providing the learner with the opportunity to acquire the proper background experience. This too often leads to another trap—the teacher attempts to give his experience to the learner. It is impossible for one to give his experiences to another person. The writer of this article cannot give his experience to the reader. Any communication that develops from reading this article will be by virtue of the fact that the reader has had similar experience in the classroom and has wondered about the same types of problems. An attempt to give the reader who lacks the necessary background experience this writer's experience is futile.

Intellectual Level of the Learner vs. Level of Instruction

The preoperational and concrete stages of intellectual development indicate that there are definite limitations in terms of the kinds of mental manipulations that the learner is able to perform during various phases of his mental growth. It is imperative that the teacher give consideration to the intellectual level of the learner and the level of mental activity required to complete the learning task successfully. If the level of the learning task is below that of the learner, he may lack motivation and fail to gain from the activity. On the other hand, if the level of the learning task is too far above that of the learner, he will probably fail to complete the task successfully. The learning task should be just difficult enough to challenge but not so difficult that success becomes an impossibility. The difficult problem is striking the right balance for each learner. Piaget's ideas offer some suggestions that may help in solving the problem.

Grouping for Science Instruction

Piaget's findings indicate that each child progresses at his own rate and the rate varies from time to time along the continuum of intellectual development. As the child's intellectual structure develops and he enters the transition zone between the preoperational and concrete operations stages, dramatic changes in intellectual abilities can take place in a very short time. This change can be seen when administering Piagetian tasks to the typical six- or seven-year-old. Prior to entering the transition zone, the child will be consistently unsuccessful in performing the tasks. As he progresses through the transitional zone, he will vacillate between logical and illogical responses. The transition zone may only last a few days or a few weeks, followed by consistent success and refinement. A teacher of second graders stated that she has observed that early in the school year the children vacillate a great deal between alternative answers and activities (preoperational stage), but toward the last half of the year the majority of the children demonstrate less vacillation and greater ability to make up their minds (concrete operational). Some children, however, will not make the transition until age eight or nine years, and the teacher is faced with the problem of dealing with a range of intellectual abilities. How can the teacher determine the intellectual level of each child and gear the level of instruction to each child?

The administration of Piagetian tasks will help the teacher to gain insights concerning the intellectual level of each child. Concern for the proper match between the intellectual development of the child and the level of instruction must lead to questioning the procedure which places one teacher with one lesson plan in a room with 30 children. Although each method of grouping for instruction has its characteristic advantages and disadvantages and the best approach may be an array of different types of groups, the current trend toward individual and individualized instruction must be given strong consideration in terms of the potential for providing instruction that is in harmony with the intellectual development of each child.

Grading, Self-Esteem and Dropouts

Every teacher realizes that there are learners who fail to learn certain concepts despite the best efforts of the learner and the teacher. Even on a one-to-one basis, when the teacher exhausts all of his techniques and the learner is sincerely interested and motivated, subsequent examination results will indicate that the learner failed to understand the concept. Piaget's findings suggest that such failure results because the level of instruction is above the level of the learner. In the early elementary grades, the problem occurs when the learner is preoperational and instruction is presented on the concrete operational level. On the junior high school, high school and college levels, the problem occurs when abstract thinking is required but the learner is still on the concrete operational level. This is especially important when one considers that early research results indicate that less than 50 percent of our population ever achieves the formal operations stage of intellectual development.

On the traditional A through F grading scale, the learner who lags behind his classmates in intellectual development will invariably receive low grades because the level of instruction will be too advanced for him. Regardless of his efforts to understand, he can only memorize and come away with grades of F's, D's and possibly some C's. Over the years this has a devastating effect on the learner. How long can a person face the interpretations that our society attaches to low grades? What happens to one's self-esteem? Does the traditional grading system contribute to the creation of dropouts? An understanding of Piaget's theory of intellectual development leads one to question seriously our traditional system of grading.

Teacher Accountability

Each person has his intellectual limitations. Newton and Einstein were intellectual giants, and it is proper that we pay them due recognition as well as try to emulate them. We must remember, however, that most people will never understand Einstein's theory of relativity, not because people do not want to learn or because we lack skilled teachers, but because their limited intellectual development makes it an impossibility. Each person should be encouraged to develop to his maximum capacity, but there must be the realization that maximum capacity for many will be something less than average.

Those who keep the tenets of intellectual development in mind will not attempt to saddle the teacher with the impossible task of teaching concepts that go beyond the level of the learner. Teachers and students must be encouraged to exert their best efforts. But any system that purports to assess the accountability of teachers will be less than rational if it fails to consider the intellectual development of the learner.

Curriculum Development and Teacher Preparation

During the 1960's modern science programs for the secondary schools were developed and implemented with financial support from the National Science Foundation. The intent was to upgrade science curricula. Major emphasis was placed on the addition of recent developments in the sciences and the understanding of science as a process—a process of inquiry. As the modern science programs were implemented in the secondary schools, a strange thing began to happen. The percentage of secondary school students enrolled in science began to decrease. An examination of the content and activities of the modern science programs indicated a definite shift toward abstract reasoning. Moreover, related teacher preparation programs had emphasized rigorous preparation in the science disciplines, with little or no attention to the intellectual development of the learner. The level of instruction in the secondary schools—especially in physics and chemistry—required students to be on the formal operations level, a level beyond that of the average secondary school student. Consequently, many students failed, science obtained a reputation for being too difficult, and enrollments declined.

In many Iowa schools where science teachers have offered a variety of science courses and have geared the instruction to the level of the students, enrollments are once again increasing. The lesson to be learned from the modern science programs of the 1960's is that curriculum development and teacher preparation must be designed and implemented in view of the best knowledge available concerning the intellectual development of the learner.

SUMMARY

Several years ago a scientist remarked that his education had left him with a very disorderly view of biology. He had been exposed to many phases of the discipline but he had trouble integrating the different parts into a coherent structure. Finally he thought about starting with the atom, and at that moment all of the pieces began to arrange themselves around the atom. Where there had been confusion and complexity, he saw organization and simplicity and he wondered why his educators had failed to teach the structure of the discipline.

Today the field of education is fragmented, chaotic and complex. The pieces are there but it is difficult to decipher the order and structure of the discipline. Piaget's ideas suggest a place to start—with the intellectual development of the learner. Like the atom in biology, it could be the key factor around which the other pieces arrange themselves in an orderly fashion.

References and Notes

For more details on Piagetian tasks and Piaget's theory, the following references are recommended:

Renner, John W., and Don G. Stafford. *Teaching Science in the Secondary School.* New York: Harper and Row, 1972. A good book to start with; contains an excellent introduction to Piaget's theory.

Phillips, John L., Jr. *The Origins of Intellect: Piaget's Theory.* San Francisco: W. H. Freeman and Company, 1969. A more detailed introduction; for the intermediate student.

Furth, Hans G. *Piaget and Knowledge: Theoretical Foundations.* Englewood Cliffs, New Jersey: Prentice-Hall, 1969. For the advanced student.